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Effects of Ozone and Sulfur Dioxide on Yield of Red Clover and Timothy

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16. ABSTRACT

A two-year study was conducted to evaluate the effects of O_3 and SO_2, both alone and in combination, on the yield and quality of a mixed crop of red clover and timothy. Sulfur dioxide had no effect on yield and there were no interactions between the pollutants. In the first year of the study, exposure to increasing concentrations of O_3 led to reductions in yield primarily through reductions in the yield of red clover; there was little effect on the growth of timothy. In the second year, red clover had become less prevalent in the stand and O_3 had no impact on total yield since the stand was dominated by the more O_3-resistant timothy. In summary, the effect of O_3 on the yield of the stand of mixed forage was not only a function of the concentration of the pollutant, but also of the relative O_3-sensitivity and contribution to the stand for each species. Evaluations of crop quality indicated that with the exception of an increase in foliar sulfur, none of the treatments altered the variables assessed.

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Effects of Ozone and Sulfur Dioxide on Yield of Red Clover and Timothy

Robert J. Kohut,* John A. Laurence, and Robert G. Amundson

ABSTRACT

Although red clover (*Trifolium pratense* L.) and timothy (*Phleum pratense* L.) are important crops in the northeast, little is known about their responses to air pollution in the field. A crop of red clover and timothy was exposed to O_3 and SO_2, both alone and in combination, in open-top chambers to evaluate effects on yield. Ozone treatments were charcoal-filtered air, nonfiltered air, and nonfiltered air to which O_3 was added to maintain concentrations 1.5 and 2.0 times ambient. Sulfur dioxide treatments were ambient and three levels of addition that simulated the concentrations and dynamics of exposures near point sources of the pollutant. Yield was based on the total biomass obtained in two harvests each year. Two studies were conducted in consecutive years. Sulfur dioxide had no effect on yield and there were no interactions between the pollutants in either study. In the first year, O_3 produced no effects on timothy but reduced the yield of clover and, consequently, the yield of the combined species. Red clover was less prevalent in the stand in the second year and O_3 had no detectable impact on the yield of clover or on total yield since the stand was dominated by the O_3-resistant timothy. The two studies indicated that effect of O_3 on yield was a function of both the concentration of the pollutant and the relative O_3-sensitivity and prevalence in the stand of the component species.

Red clover (*Trifolium pratense* L.) and timothy (*Phleum pratense* L.) are important hay and forage species in the northeastern USA and are commonly grown together (New York State Coll. of Agric. and Life Sci., 1984). Red clover is a short-lived perennial that makes an important contribution to a mixed stand due to its nitrogen fixing properties. Timothy is considered intermediate in longevity and can be a major contributor to the productivity of a stand throughout its duration. When grown together, the two species form a highly productive stand with community dynamics that can lead to the elimination of red clover over a period of 2 to 3 yr.

The response of red clover or timothy to either ozone (O_3) or sulfur dioxide (SO_2) has received limited attention. In an evaluation of the foliar responses of six species of forage legumes to O_3, red clover was found to be the most sensitive (Brennan et al., 1969). Comparing the effects of O_3 on net photosynthesis in three crop and four tree species, Reich and Amundson (1985) found red clover to be more severely affected than soybean [*Glycine max* (L.) Merr.] or wheat (*Triticum aestivum* L.) at equivalent cumulative hours of exposure and the most sensitive of the seven species evaluated. In studies with timothy, SO_2 was found to reduce tiller and leaf production (Ashendon and Williams, 1980) and to reduce translocation to roots and subsequent root weight (Jones and Mansfield,

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1982). Youngner et al. (1981) assessed the response of timothy to both O_3 and SO_2. They found that ambient levels of O_3 reduced yield and tiller production, that no significant effects were produced by SO_2, and that there were no interactive effects.

Because the red clover/timothy forage crop is economically important in the northeast and because little is known about the impacts of air pollution on it, two field studies were conducted with the crop as a part of the National Crop Loss Assessment Network (NCLAN) program. The objective of the studies was to evaluate dose-response relationships for the yield of a crop of red clover and timothy exposed to O_3 alone, SO_2 alone, and the two pollutants in combination.

MATERIALS AND METHODS

Cultural Practices

A stand of red clover (cv. Arlington) and timothy (cv. Champlain) was planted on 16 Aug. 1983. The field had been pretreated with Roundup herbicide [41% isopropylamine salt of *N*-(phosphono-methyl) glycine] at 7.1 L ha^{-1} and fertilized with 10-20-20 (N-P-K) at 227 kg ha^{-1}. Seed of the two species was combined at equal weights and applied at a rate of 14.75 kg ha^{-1}. The timothy/clover seed ratio was approximately 4.5:1. Prior to planting, the clover seed was inoculated with a commercial rhizobium product (Nitragin) at the rate of 41 g kg^{-1} of seed.

Soils at the research site are in the Collamer (Glossaquic Hapludalfs) and Niagara (Aeric Ochraqualfs) series and are characterized as silt loams. Tensiometers were placed in all plots at a depth of 30.5 cm to monitor soil moisture. Tensiometers were read twice each week and all plots irrigated when readings exceeded −0.07 MPa in half of the plots. The plots were irrigated on 20 July and 10 Aug. 1984 and 11 June and 13 Aug 1985. At each irrigation, the plots received 5.0 cm of water in 1984 and 2.5 cm of water in 1985. Malathion (*O,O*-dimethyl phosphorodithoate of diethyl mercaptosuccinate) (25% a.i. mixed at 2.5 g L^{-1}) was applied to control aphids on 28 July 1984 and on 11 and 30 July 1985. Pellets of slug poison (3.25% metaldehyde) were placed in each plot on 3 Aug. 1985.

Pollutant Treatments and Monitoring

Open-top chambers were used to expose the crop to four levels of O_3, four levels of SO_2, and all combinations of the two pollutants. All treatments were replicated. The O_3 treatments consisted of charcoal-filtered air (CF), nonfiltered air (NF), and nonfiltered air with the proportional addition of O_3 to attain 1.5 and 2.0 times the ambient concentration (treatments designated NF × 1.5 and NF × 2.0, respectively). Additions were made for 12 h d^{-1} (0800-2000 h EDT) when ambient O_3 concentrations were greater than 0.03 μL L^{-1}; additions were terminated during periods of rain. Blowers for all chambers were turned off from 2300 to 0500 h EDT to provide a period of still air for dew formation overnight.

Sulfur dioxide treatments simulated the concentration, duration, and frequency dynamics associated with exposures from point sources. Ambient SO_2 monitoring data were obtained from the Tennessee Valley Authority (TVA) for the Shawnee Steam Plant for the 1976, 1978, and 1982 growing seasons. Since each year represented a different level of emission control at the power plant, the frequency distribution of concentrations and the exposure dynamics for each year served as the basis for developing the SO_2 treatments used in the study. However, no attempt was made to simulate the actual exposures or patterns of exposure that occurred in a specific year.

Table 1. Frequency distributions of the hourly concentrations of SO_2 in the target treatments in 1984 and 1985.

SO_2 conc., μL L^{-1}	1984 Treatments			1985 Treatments		
	High	Medium	Low	High	Medium	Low
0.00	2548	2630	2688	2376	2396	2455
0.05	131	76	48	–	–	–
0.10	18	21	10	16	33	31
0.15	11	10	2	20	20	13
0.20	8	2	1	13	10	5
0.25	5	4	1	10	8	3
0.30	2	1		10	7	5
0.35	5	3		10	6	3
0.40	4	2		8	5	3
0.45	3	0		8	6	2
0.50	1	1		10	6	
0.55	2			8	4	
0.60	3			7	5	
0.65	0			6	4	
0.70	3			4	4	
0.75	1			4	3	
0.80	1			5	3	
0.85	2			3		
0.90	2			2		
Total hours of exposure	202	120	62	144	124	65

The SO_2 exposure regimes from the TVA monitoring data were used to develop three frequency distributions of hourly concentrations of SO_2 for use in the 1984 study. Several modifications were made in the treatment levels for 1985; the lowest SO_2 frequency distribution was dropped, the remaining two distributions were slightly modified, and a new distribution with higher levels of SO_2 exposure was developed. The frequency distributions of the hourly exposure concentrations for the SO_2-addition treatments in both years are presented in Table 1. The fourth treatment level each year consisted of no addition of SO_2. The frequency distributions of SO_2 for each treatment were used to create a suite of exposures of varying hourly concentrations and from 3 to 6 h in duration. Exposure events were created by selecting the exposures from each of the treatments that would be conducted on the same day. There were 35 exposure events in 1984 and 30 in 1985. Examples of the exposures and the exposure events are presented in Table 2. Exposure events were assigned to either the first or second harvest period to ensure that there was an equal distribution of hours of exposure and maximum concentrations of SO_2 for each treatment in the two periods. Within each harvest period, the SO_2 exposure event that occurred on a given day was selected at random.

Ozone was monitored with Monitor Labs Model 8410 analyzers (Monitor Labs, San Diego, CA) and SO_2 with TECO Model 43 analyzers (Thermo Electron Corp., Hopkinton, MA). All analyzers were subject to weekly zero and span checks as part of the NCLAN quality assurance program. Pollutant monitoring was conducted with a time-sharing system in which each observation was 1.5 min in duration and each plot was sampled three times each hour. The sample air stream was split after passing through the sequencing value of the system and directed to both the O_3 and SO_2 analyzers. All sample lines were Teflon. Sample line efficiencies for each gas were determined two times during the year and were taken into account both during the fumigations and in the subsequent reduction of monitoring data. Data were recorded with a Hewlett-Packard Model 85 computer and data logger (Hewlett Packard, Palo Alto, CA) with strip-chart recorders used as back-up.

The experiment was a 4 × 4 × 2 factorial requiring 32 open-top chamber plots; treatments were randomly assigned to 16 plots in each of two blocks. During 1984, O_3 treatments were initiated on 28 June and terminated on 28 Sept.; O_3 was added

Table 2. Examples of SO_2 exposures conducted in 1985 illustrating the dynamics of concentration and duration that were incorporated into the treatments.

Exposure no.	Exposure hour	Exposure conc.		
		High	Medium	Low
		μL L^{-1}		
No. 2	1	0.65	0.35	0.25
	2	0.80	0.75	0.45
	3	0.75	0.65	0.35
	4	0.50	0.30	0.20
No. 7	1	0.50	0.35	0.15
	2	0.70	0.35	0.25
	3	0.75	0.60	0.15
	4	0.55	0.50	0.10
	5	0.45	0.15	–
No. 11	1	0.50	0.35	–
	2	0.60	0.50	0.25
	3	0.35	0.10	–
	4	0.30	–	–
No. 14	1	0.30	0.20	0.10
	2	0.60	0.60	0.40
	3	0.55	0.30	0.10
	4	0.35	0.10	–
	5	0.15	–	–
No. 20	1	0.10	0.10	–
	2	0.35	0.20	–
	3	0.25	0.15	–
	4	0.20	0.10	–
No. 24	1	0.10	0.10	0.10
	2	0.30	0.25	0.15
	3	0.20	0.15	0.10
	4	0.15	–	–

on 83 d and SO_2 exposures conducted on 35 d during this 98-d period. In 1985, O_3 treatments were initiated on 14 June and concluded on 9 Oct. During this 118-d period, O_3 additions were made on 91 d and SO_2 exposures were conducted on 30 d.

Harvests

In the spring of each year, the forage stand was evaluated for uniformity and sites for 32 plots were selected. The experimental plots used in 1984 were not used in 1985 due to limited regrowth after the final harvest in 1984. Before treatments were initiated each year, the experimental plots were harvested at the time of clover flowering to establish baseline levels of forage production and the contribution of each species to the biomass of the stand. Harvests to assess the effects of the treatments were conducted twice during each year; 8 Aug. and 4 Oct. 1984 and 12 Aug. and 9 Oct. 1985.

Harvest data were obtained from two permanently marked 0.5 m^2 quadrats in each chamber and ambient plot. Plants in each quadrat were cut 10 cm above the ground and separated by species. Plant material was oven-dried at 80 °C for 48 h and weighted. Dry-weight yields were obtained for the individual and combined species at each harvest and for the two combined harvests.

Statistical Analysis

Harvest data for each year were evaluated using analysis of variance to determine whether there were significant main or interactive effects of the pollutant treatments on yield. Analyses were conducted on the yields of the individual and combined

Table 3. Treatment-level characterizations of the O_3 exposure regimes in the 1984 and 1985 red clover and timothy studies.

Treatment	12-h			7-h			Daily 1-h high conc.			h > 0.08	h > 0.12
	Avg.	Max.	2nd Max.	Avg.	Max.	2nd Max.	Avg.	Max.	2nd Max.		
	μL L^{-1}										
					1984 Exposure regime						
CF	0.019	0.041	0.037	0.022	0.048	0.042	0.037	0.082	0.078	1	0
AA	0.036	0.070	0.069	0.040	0.081	0.076	0.058	0.086	0.085	7	0
NF	0.036	0.067	0.064	0.041	0.076	0.073	0.052	0.085	0.084	8	0
NF × 1.5	0.050	0.100	0.096	0.057	0.112	0.110	0.075	0.127	0.126	265	8
NF × 2.0	0.062	0.127	0.127	0.071	0.146	0.139	0.094	0.169	0.160	512	148
					1985 Exposure regime						
CF	0.019	0.047	0.037	0.022	0.052	0.045	0.038	0.077	0.076	0	0
AA	0.036	0.065	0.064	0.040	0.069	0.068	0.052	0.091	0.087	13	0
NF	0.036	0.067	0.066	0.040	0.072	0.071	0.052	0.102	0.090	16	0
NF × 1.5	0.048	0.094	0.091	0.054	0.108	0.103	0.072	0.163	0.126	207	5
NF × 2.0	0.062	0.135	0.133	0.070	0.146	0.145	0.098	0.231	0.192	548	156

Table 4. Treatment-level characterizations of the SO_2 exposure regimes in the 1984 and 1985 red clover and timothy studies.

Treatment	24-h avg. for fumigation days	24-h avg. for all days	Avg. daily 1-h max. for all days	Max. 1-h	2nd Max. 1-h	Cumulative μL L^{-1} h†
	μL L^{-1}					
			1984 Exposure regime			
Ambient	0.004	0.002	0.016	0.115	0.108	2.24
Low	0.005	0.003	0.027	0.162	0.158	2.89
Medium	0.008	0.005	0.049	0.387	0.373	4.60
High	0.016	0.011	0.109	0.833	0.728	9.30
			1985 Exposure regime			
Ambient	0.004	0.002	0.013	0.121	0.079	1.41
Low	0.010	0.006	0.059	0.484	0.435	4.07
Medium	0.025	0.014	0.127	0.775	0.767	10.75
High	0.035	0.020	0.154	0.970	0.867	15.14

† Calculated from the average SO_2 concentration for each fumigation.

species at each harvest and for the combined harvests. Dose-response functions were produced using regression analysis on the total biomass harvested from the treatment plots each year. Since the study was conducted as a part of NCLAN, regression analysis used both the Weibull model that had been adopted by the program (Rawlings and Cure, 1985) and alternative models.

RESULTS

Pollutant Treatments

The hourly O_3 and SO_2 monitoring data were analyzed to define the exposure treatments. The treatment-level characterizations of the O_3 exposure regimes for both years of the study are presented in Table 3. The average, maximum, and second maximum of the 7-h (1000–1700 h EDT) and 12-h (0800–2000 h EDT) and of the daily 1-h peak concentrations of O_3 and the number of hours above 0.08 and 0.12 $\mu L\ L^{-1}$ were indices of exposure calculated in all NCLAN studies. The SO_2 treatments were defined by calculating the average 24-h and daily 1-h peak concentrations, the first and second 1-h maximum concentrations, and the cumulative $\mu L\ L^{-1}$-h. Exposure data for SO_2 are presented in Table 4.

Effects on Yield

Analysis of variance indicated that in 1984 there were no significant main or interactive effects of SO_2 on the yield of clover, timothy, or the combined species in either the individual harvests or in the total harvest for the year. Ozone produced significant effects on the yield of clover and the combined species in both of the harvests and in the total for the year. At no time did O_3 produce significant effects on the yield of timothy. The total yield for 1984 and its allocation between timothy and red clover are presented in Table 5. The analysis of variance for the total yield is presented in Table 6.

Regression analysis was used to develop dose-response functions for the response of the crop to O_3 in 1984. Since analysis of variance indicated that there were no significant main or interactive effects of SO_2, treatments were pooled to develop a response function for the effect of O_3 on yield. The high degree of variability in the plot-level yield data led to difficulty in producing a response function. Analyses were conducted using 29 indices of yield generated from the harvest data and 23 measures of O_3 exposure. Sets of air quality variables that maximized the R^2 value were evaluated using all possible regressions. In no case did R^2 exceed 0.50 without the use of more than four independent variables. Consequently, it was decided to select the most reasonable regression that would predict the total biomass harvested from the plots. The linear regression incorprated both the 12-h and 7-h average concentrations of O_3 and the proportion of clover in the plot prior to the initiation of the treatments.

The Weibull model was used with the 7- and 12-h average concentrations of O_3 to produce response functions. In both cases, the confidence intervals for the C parameter of the model are quite broad, indicating uncertainty about the shape of the curve. The linear and Weibull dose-response functions for the 1984 exposures are presented in Table 7.

Analysis of variance indicated that in 1985 neither O_3 nor SO_2 had a significant effect on the yield of the individual or combined species in either harvest or for the year (Table 6) and no dose-response functions were produced. The total biomass harvested in 1985 and its allocation between timothy and red clover are presented in Table 8.

Table 5. Biomass yield data from red clover and timothy harvested from open-top chambers in 1984.

SO_2 Treatment	O_3 Treatment				
	CF	NF	NF × 1.5	NF × 2.0	Mean
	kg ha^{-1}				
	Yield of red clover and timothy combined				
Ambient	3278	3718	2240	2194	2858
Low	4492	4358	2962	2878	3672
Medium	3012	5096	3472	2194	3442
High	4134	3746	2550	2838	3316
Mean	3730	4230	2806	2526	
	Yield of timothy				
Ambient	1484	774	572	584	848
Low	538	794	894	1240	866
Medium	278	320	200	1138	484
High	178	454	718	588	484
Mean	620	586	596	882	
	Yield of red clover				
Ambient	1794	2944	1668	1630	2010
Low	3954	3564	2068	1638	2806
Medium	2734	4776	3272	1056	2958
High	3956	3292	1832	2250	2832
Mean	3110	3644	2210	1644	

Table 6. Analysis of variance tables for the effects of O_3 and SO_2 on the total yield of red clover and timothy in 1984 and 1985.

Source of variation	df	Sum of squares	Mean square	F	Significance†
		Analysis of variance for 1984			
O_3	3	99 197.9	33 065.9	4.50	$P < 0.05$
SO_2	3	23 811.1	7 937.0	1.08	NS
Block	1	68 501.9	68 501.9	9.32	$P < 0.01$
$O_3 \times SO_2$	9	28 596.9	3 177.4	0.43	NS
Error	15	110 192.8	7 346.2		
		Analysis of variance for 1985			
O_3	3	6 012.3	2 004.1	0.50	NS
SO_2	3	10 317.3	3 439.1	0.86	NS
Block	1	2 702.7	2 702.7	0.67	NS
$O_3 \times SO_2$	9	6 553.8	728.2	0.18	NS
Error	15	60 147.0	4 009.8		

† NS indicates not significant.

DISCUSSION

These studies of O_3 and SO_2 effects on the productivity of a two-species stand of forage illustrate the importance of both the sensitivity of each species to the pollutants and the composition of the stand in determining the responses to the treatments. A mixed stand of clover and timothy has a limited life in the northeast since clover is rapidly reduced in abundance due to competition and root diseases and contributes little to the productivity of the stand the second year after establishment (New York State Coll. of Agric. and Life Sci., 1984). The

Table 7. Linear and Weibull dose-response functions for the effects of O_3 on the total yield of clover and timothy in 1984. All yields in kg ha^{-1} and all concentrations of O_3 in $\mu L\ L^{-1}$.

Linear

$$Yield = 3267.37 + 920.69\ (O_312) - 829.72\ (O_37) + (3272.12 \times CL)$$

where O_312 = the 12-h average O_3 concentration
O_37 = the 7-h average O_3 concentration
CL = the proportion, by weight, of clover in the initial stand

Weibull

$$Yield = 4119.19 \exp - (O_312/0.072)^{4.034}$$

where O_312 is the 12-h average O_3 concentration

$$Yield = 4140.33 \exp - (O_37/0.083)^{3.882}$$

where O_37 is the 7-h average O_3 concentration

relative sensitivity of clover to O_3 that was observed in this study may also contribute to its decline in the stand.

In 1984, the total yield of the stand was reduced by exposure to O_3; assessment of the effects of O_3 on the component species indicated that the yield of clover was significantly reduced, whereas that of timothy remained unaffected. The dominance of clover in the stand and its sensitivity to O_3 resulted in the reductions in yield that were observed. The importance of clover in producing this reduction in yield is also evidenced by the inclusion of the pretreatment level of clover as a significant variable in the linear dose-response function. The greater sensitivity of clover to O_3 in this study is similar to that found by Bennett and Runeckles (1977) for crimson clover (*T. incarnatum* L.) growing in a mix with annual ryegrass (*Lolium multiflorum* Lam.) and by Blum et al. (1983) for ladino clover (*T. repens* L.) in a mix with tall fescue (*Festuca arundinacea* Schreb.).

The exposures conducted in 1985 were on plots that had not been exposed previously to the pollutants. The lack of a treatment effect that year can be attributed to three factors operating in concert. First, the stand was in its second year and exhibited an even higher degree of heterogeneity in stocking and composition than in the initial year, thereby making it more difficult to detect a significant effect of the treatments. Second, clover, the more O_3-sensitive species, was declining in the stand as is expected in the second year of a clover/timothy mix. Third, although timothy was more resistant to O_3 than was clover, its yield did not increase to compensate for the decline in clover and overall stand productivity was decreased. Acting together, these factors resulted in a highly variable stand of forage with declining productivity that was dominated by an O_3-resistant species. Consequently, no statistically significant effects on yield were produced by either pollutant in 1985.

Yields on the plots used in the second study were considerably less than were those of the plots in the first study (Tables 5 and 8). The differences were primarily the result of a reduction in the productivity of clover since the yield of timothy in 1985 was generally either comparable to or greater than that in 1984. The role of O_3 in accelerating this process cannot be assessed at this time. Only through the use of a multivariate regression equation was it possible to develop a dose-response function that described the effects of O_3 on production; that this relationship is not strongly defined is evidenced by the low

Table 8. Biomass yield data from red clover and timothy harvested from open-top chambers in 1985.

SO_2 Treatment	O_3 Treatment				Mean
	CF	NF	NF × 1.5	NF × 2.0	
	kg ha^{-1}				
	Yield of red clover and timothy combined				
Ambient	2259	1609	2229	1289	1846
Low	1515	1554	1819	1456	1586
Medium	1409	1516	1267	1567	1440
High	1668	1698	1532	1448	1586
Mean	1713	1594	1711	1440	
	Yield of timothy				
Ambient	880	1007	750	250	722
Low	584	382	612	568	536
Medium	811	980	1083	1033	976
High	602	1256	952	810	905
Mean	719	906	849	665	
	Yield of red clover				
Ambient	1380	602	1479	1039	1125
Low	932	1172	1207	888	1049
Medium	599	537	185	534	463
High	1065	443	580	638	681
Mean	994	689	863	774	

R^2 value for the regression. The high degree of variability that existed among the plots in the production of biomass and in the contribution of each species to that production made it difficult to assess the normal changes in the stand and to evaluate the effects of the treatments.

Unlike most research assessing the effects of SO_2 on vegetation, the SO_2 exposures in this study were designed to simulate the dynamics of exposure concentration, duration, and frequency associated with a point source. Short-term exposures of up to 0.970 $\mu L\ L^{-1}$ occurred in the study. Sulfur dioxide, either alone or in combination with O_3, had no significant effect on the yield of either species. This illustrates the importance of the dynamics of exposures in the field in influencing the responses of plants to SO_2 and suggests the need for additional research that incorporates realistic exposure regimes.

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Soil Microbial Populations and Activities under Conventional and Organic Management

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ABSTRACT

Evaluation of microbial populations and activities, and their relationship to N cycling in soils under organic and conventional farm management was conducted in eastern Nebraska in 1981 and 1982, on an experiment initiated in 1975. The experimental treatments consisted of 3 × 4 factorial with three management systems (organic, fertilizer only, and fertilizer plus herbicide) for a 4-yr grain/legume crop rotation plus one treatment of continuous corn (*Zea mays* L.) receiving fertilizer, herbicide, and insecticide (including one subplot without insecticide). Soil physical, chemical, and microbiological characterizations were made at soil depth intervals of 0 to 7.5, 7.5 to 15, and 15 to 30 cm. Soil chemical properties were significantly influenced by chemical management, primarily the application of beef (*Bos taurus*) feedlot manure in the organic management system. Total organic C, Kjeldahl N, and potentially mineralizable N in manure-amended surface soils (0–7.5 cm) were 22 to 40% greater than nonmanured soils receiving fertilizer and/or herbicide. Soluble P levels were eightfold greater in manure-amended surface soils, and soil nitrate levels after harvest in 1981 were two- to threefold greater to a depth of 30 cm than nonmanured chemical treatments. Soil microbial biomass, bacterial and fungal counts, dehydrogenase activity, and CO_2 evolution were greater in soils planted to oat/clover (*Avena sativa* L./*Trifolium pratense* L. + *Melilotus officinalis* Lam.) and treatments receiving manure. Increases in microbial populations and their activities paralleled increases in soil organic C content, Kjeldahl N, and water-filled pore space. Differences in N_2 fixation and denitrification between crops and management systems were minimal—possibly resulting from suboptimal water availability at midseason sampling. No significant differences were found in measured soil physical, chemical, or biological properties due to herbicide or insecticide at field application rates.

Increased monoculture production of cash grain crops and greater reliance on chemical fertilizers and pesticides to maintain grain yields are related, in part, to declining soil productivity and increased environmental contamination in the USA (Pimentel et al., 1978; Power and Follett, 1987). Motivation for shifting from chemically intensive management to alternative practices includes (i) concern for protecting soil, human, and animal health from the potential hazards of pesticides; (ii) concern for protecting environmental and soil resources; and (iii) a need to lower production costs. Organic farming systems rely upon legume-containing crop rotations, crop and animal residues, and mechanical cultivation to maintain soil tilth and nutrient supply, and control insects, weeds, and other pests (USDA, 1980). The use of synthetic chemical fertilizers and pesticides is thought harmful to microorganisms and other life forms and is avoided (Wolf, 1977).

Short-term effects connected with use of fertilizers or pesticides are generally related to disturbances of chemical and biological balance in soil. Herbicide use is known to selectively suppress activity of microorganisms responsible for N_2 fixation and nitrification for 4 to 12 wk in soil (Bollen, 1961; Chandra, 1964). Use of chemical fertilizers and pesticides at recommended application rates, however, has few direct long-term effects on microbial populations and their activity (Wainwright, 1978; Goring and Laskowski, 1982; Biederbeck et al., 1987). Pesticide decomposition is frequently faster in soils high in organic matter, presumably because of more vigorous microbial activity. Use of herbicides can reduce total microbial populations in soil (Greaves et al., 1976), which some researchers attribute to reduced input of organic residues resulting from weed control (Wainwright, 1978).

In management systems where synthetic chemical use is reduced or eliminated, the function of soil microorganisms becomes a major determinant of nutrient cycling and plant growth. Microbial mineralization of 2 to 5% of soil organic matter each year largely supplies the N needed for crop plants. Legume-containing crop rotations or animal manures are used to supply N for succeeding crops. Recovery of legume-fixed N by nonleguminous grain crops varied from 10 to 50%, and varies with climate and microbial activity (Bartholomew, 1971; Ladd et al., 1981).

Shifts in microbial numbers and activity in soil are often related to changes in C inputs to soil as a result of management-related changes in crop type or residue addition. Soil microbial populations are increased by addition of animal manures or by synthetic fertilizers where crop residue production and soil organic-matter levels are simultaneously increased (Martyniuk and Wagner, 1978). Farming management systems that increase belowground

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